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(54) **BEAMFORMING METHOD AND APPARATUS, AND MEDICAL IMAGING SYSTEM**

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G01S 7/52   (2006.01)
G10K 11/34   (2006.01)

(52) **U.S. Cl.**
CPC *G01S 7/52019* (2013.01); *G10K 11/346* (2013.01)

(58) **Field of Classification Search**
USPC 600/407, 437, 443, 459, 447
See application file for complete search history.

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(57)   **ABSTRACT**

A beamforming method includes generating a control signal for implementing a delay time for each of a plurality of transducers of each of a plurality of two-dimensional (2D) transducer-arrays, transmitting the control signal to a plurality of driving units respectively corresponding to the plurality of 2D transducer-arrays via an interposer that electrically connects the plurality of 2D transducer-arrays to each other, and driving each 2D transducer-array of the plurality of 2D transducer-arrays with a corresponding driving unit of the plurality of driving units according to the control signal transmitted via the interposer.
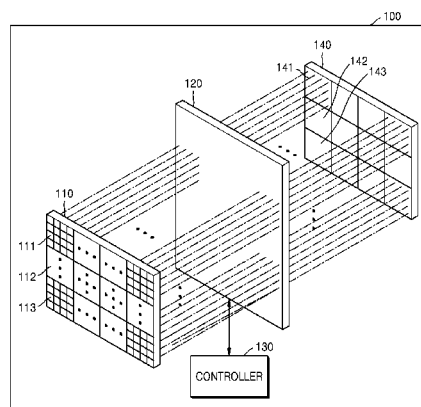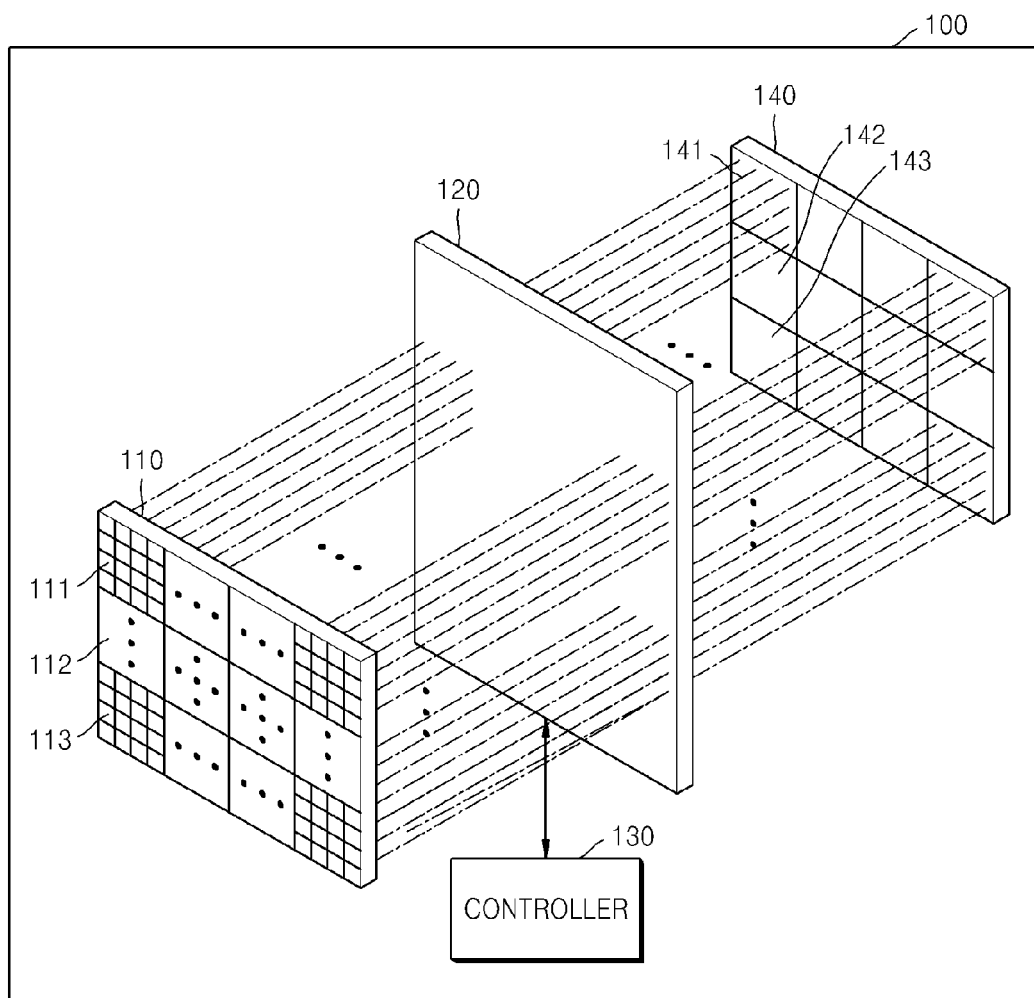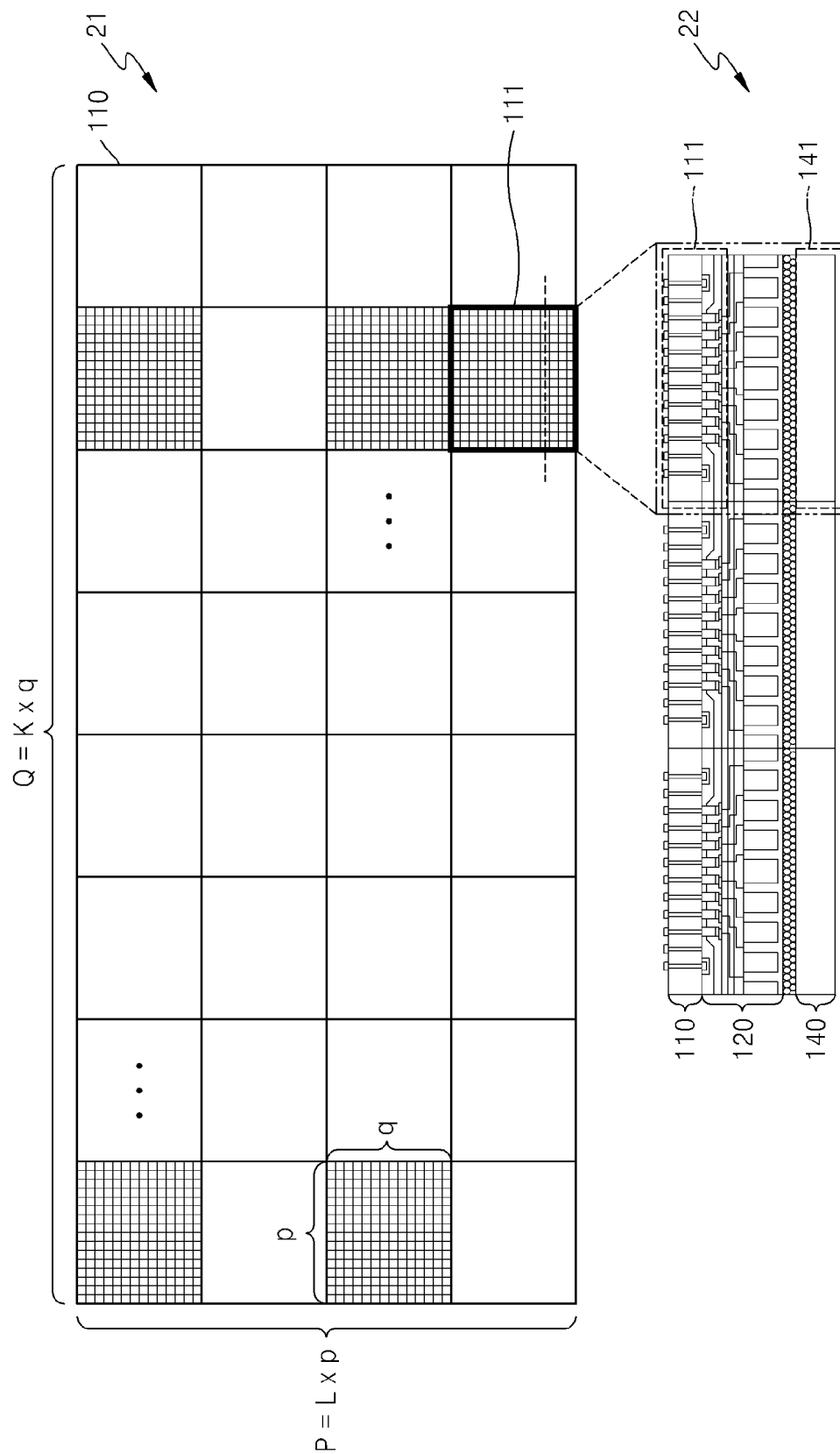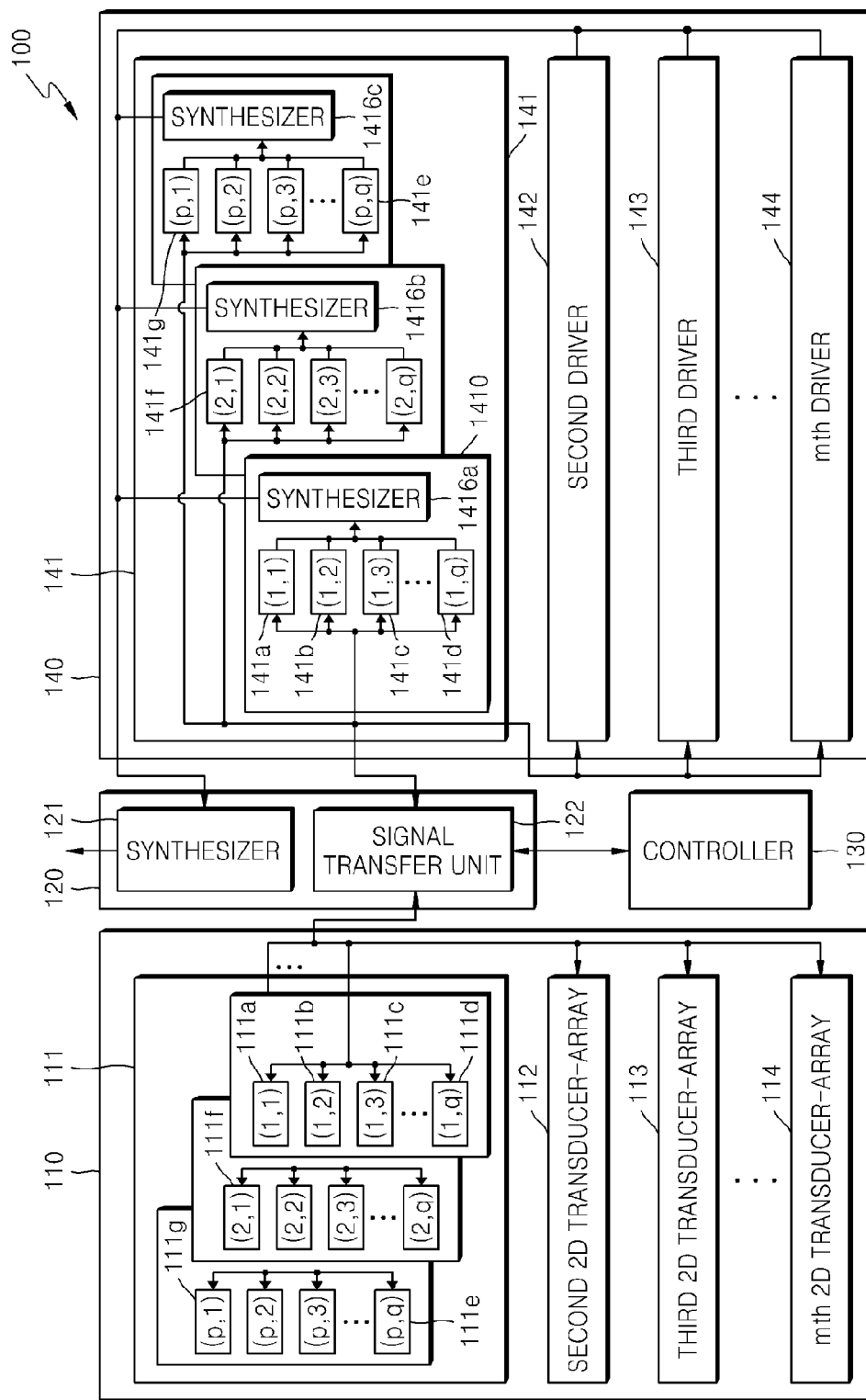
21 Claims, 11 Drawing Sheets

FIG. 1

FIG. 2

FIG. 3

FIG. 4

1410

1411 DELAYER

1412 SWITCH DEVICE

1413 SIGNAL GENERATOR

1414 TRANSMITTING /RECEIVING SWITCH UNIT

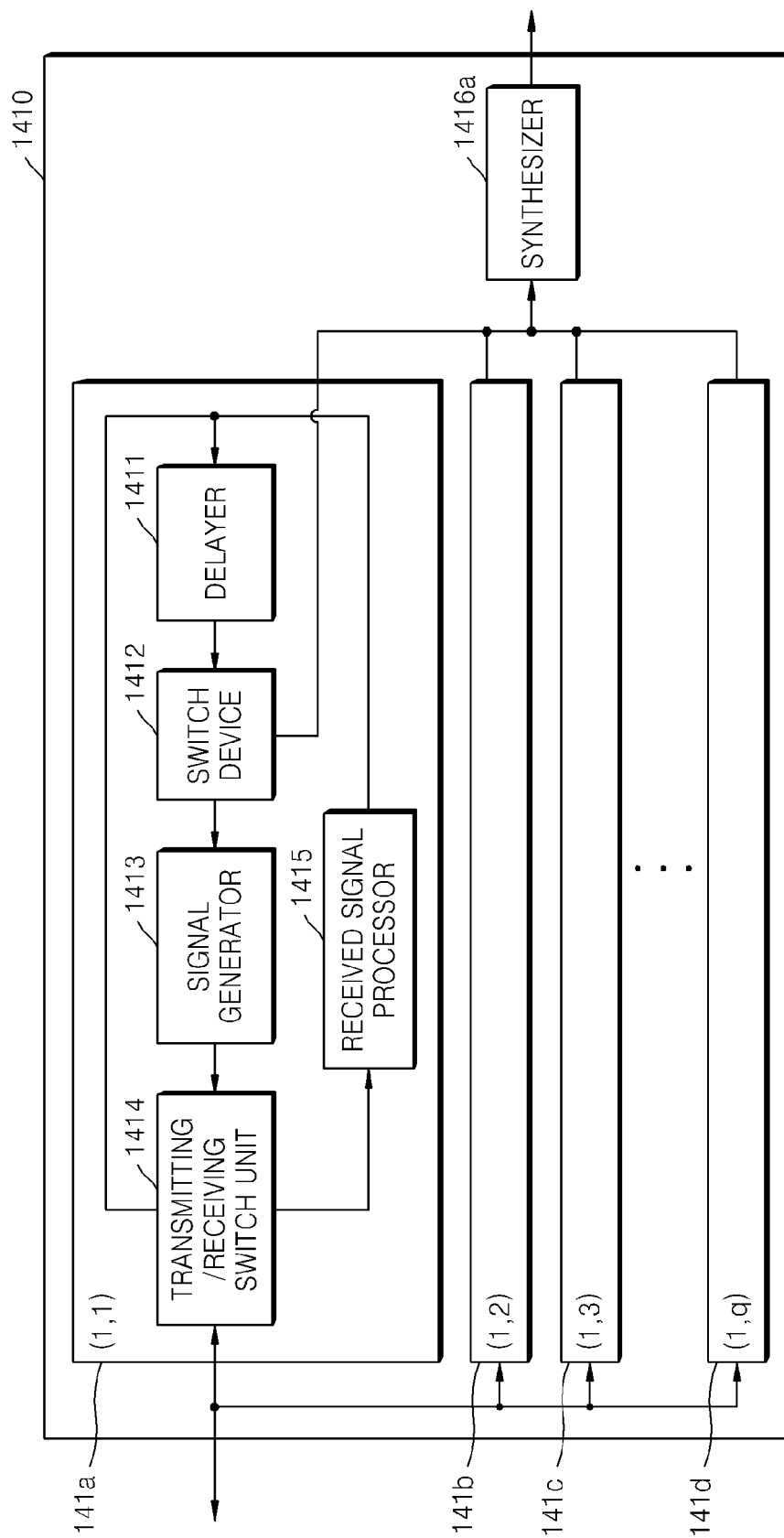1415 RECEIVED SIGNAL PROCESSOR

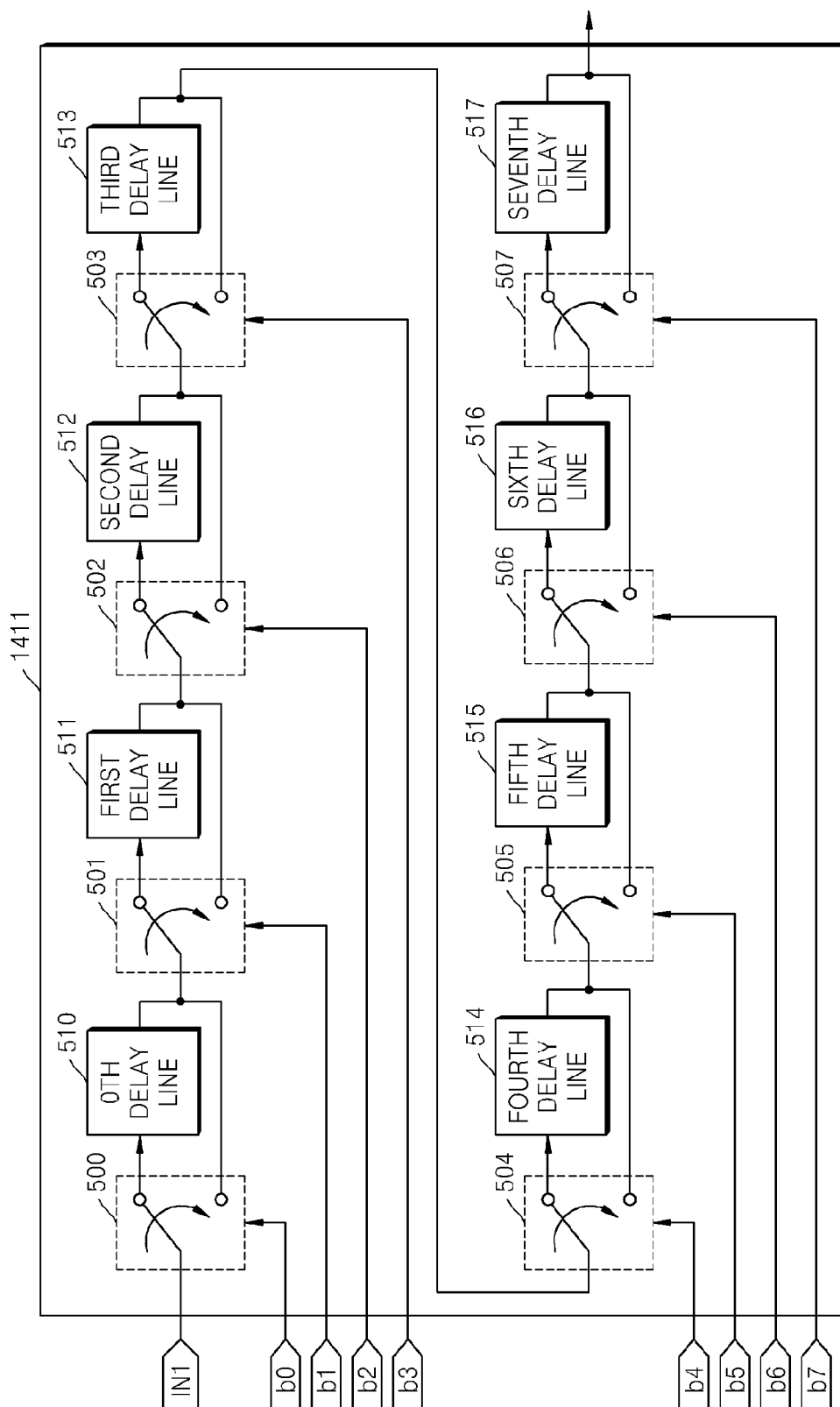1416a SYNTHESIZER

(1,1)

(1,2)

(1,3)

(1,q)

141a

141b

141c

141d

. . .

FIG. 5

FIG. 6

FIG. 7

FIG. 8

100

A PLURALITY OF 2D
TRANSDUCER-ARRAYS   110

INTERPOSER   120

CONTROLLER   130

A PLURALITY OF
DRIVING UNITS   140

ADC   160

TRANSMITTING
DIGITAL BEAMFORMER   152

RECEIVING DIGITAL
BEAMFORMER   154

150

FIG. 9

FIG. 10

FIG. 11

```
                                                    ┌──────────────┐
                                                    │  DISPLAY UNIT│ ─220
                                                    └──────────────┘

┌─────────────┐     ┌─────────────┐             ┌──────────────┐
│ BEAMFORMING │ ──→ │  DIAGNOSTIC │ ──→ ●  ──→  │ STORAGE UNIT │ ─230
│  APPARATUS  │     │    IMAGE    │             └──────────────┘
│             │     │  GENERATOR  │
└─────────────┘     └─────────────┘             ┌──────────────┐
     100                 210                     │ OUTPUT UNIT  │ ─240
                                                 └──────────────┘
```

200

FIG. 12

```
                    ( START )
                        │
                        ▼
┌─────────────────────────────────────────────────────┐
│   GENERATE CONTROL SIGNAL FOR IMPLEMENTING           │
│   DELAY TIME FOR EACH OF TRANSDUCERS INCLUDED        │── 1201
│   IN PLURALITY OF 2D TRANSDUCER-ARRAYS               │
└─────────────────────────────────────────────────────┘
                        │
                        ▼
┌─────────────────────────────────────────────────────┐
│   TRANSMIT CONTROL SIGNAL TO PLURALITY OF            │
│   DRIVING UNITS RESPECTIVELY CORRESPONDING TO        │── 1202
│   PLURALITY OF 2D TRANSDUCER-ARRAYS VIA INTERPOSER   │
└─────────────────────────────────────────────────────┘
                        │
                        ▼
┌─────────────────────────────────────────────────────┐
│   DRIVE EACH OF PLURALITY OF 2D TRANSDUCER-ARRAYS    │── 1203
│   ACCORDING TO  CONTROL SIGNAL                       │
└─────────────────────────────────────────────────────┘
                        │
                        ▼
                    (  END  )
```
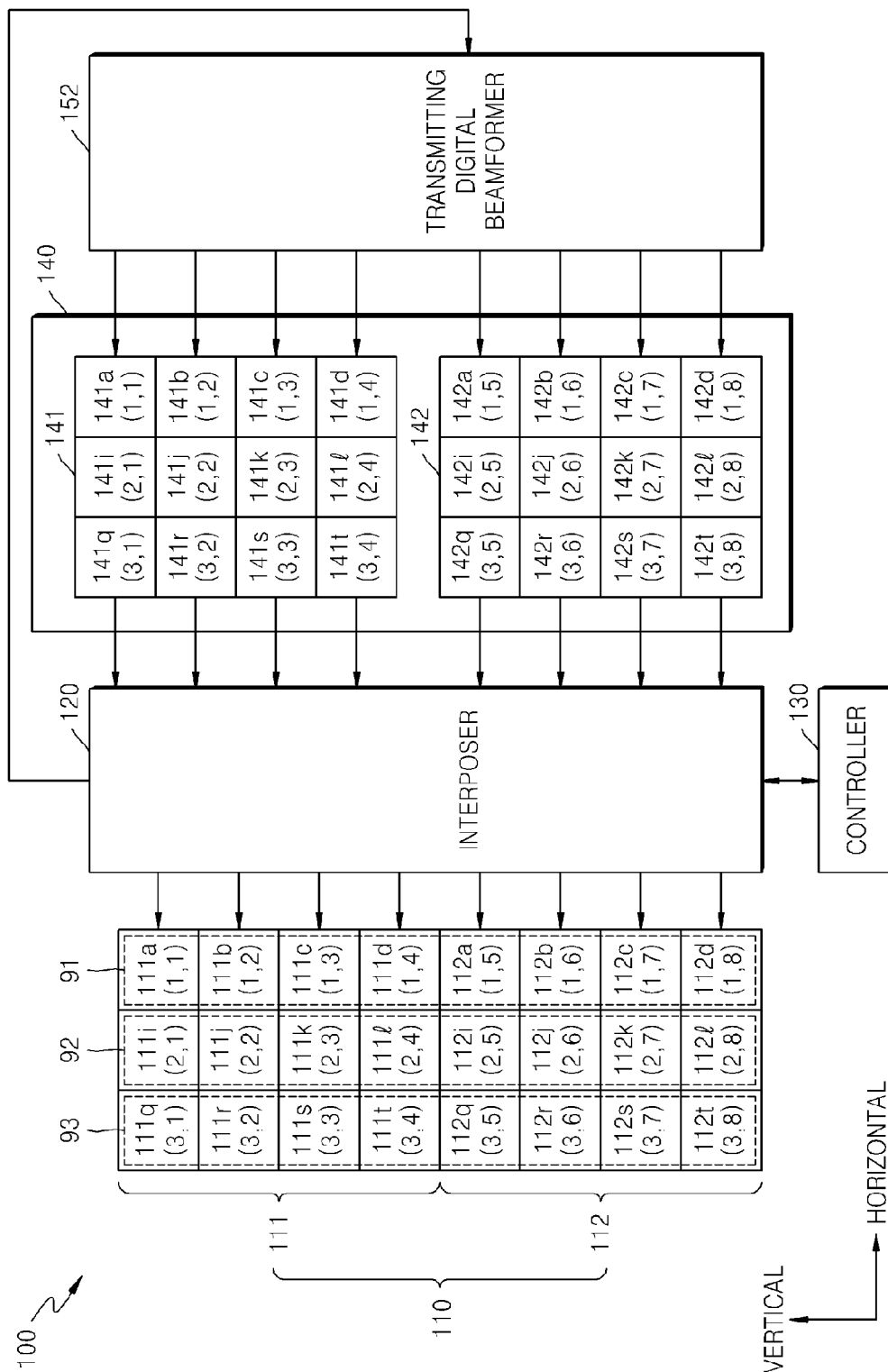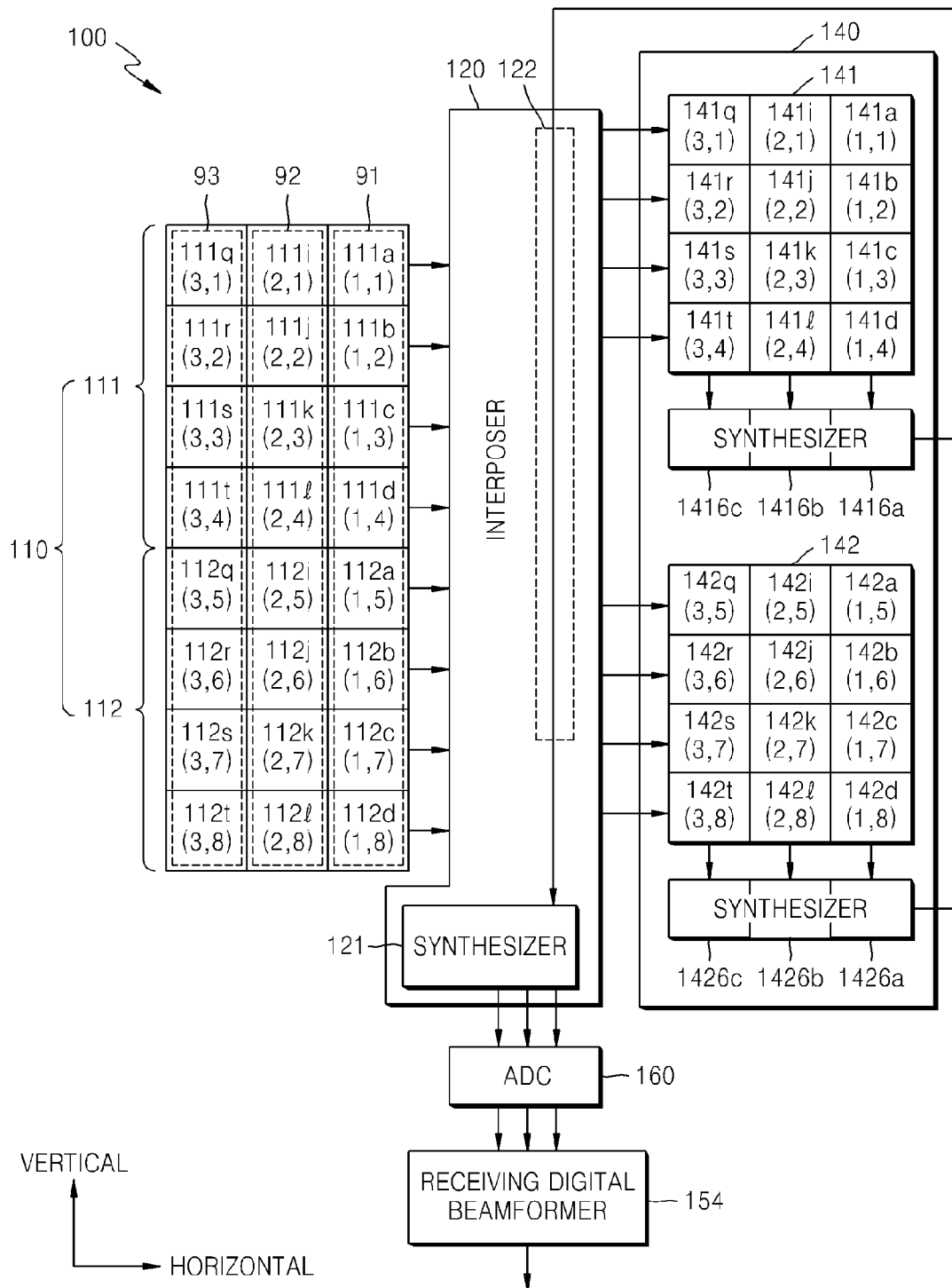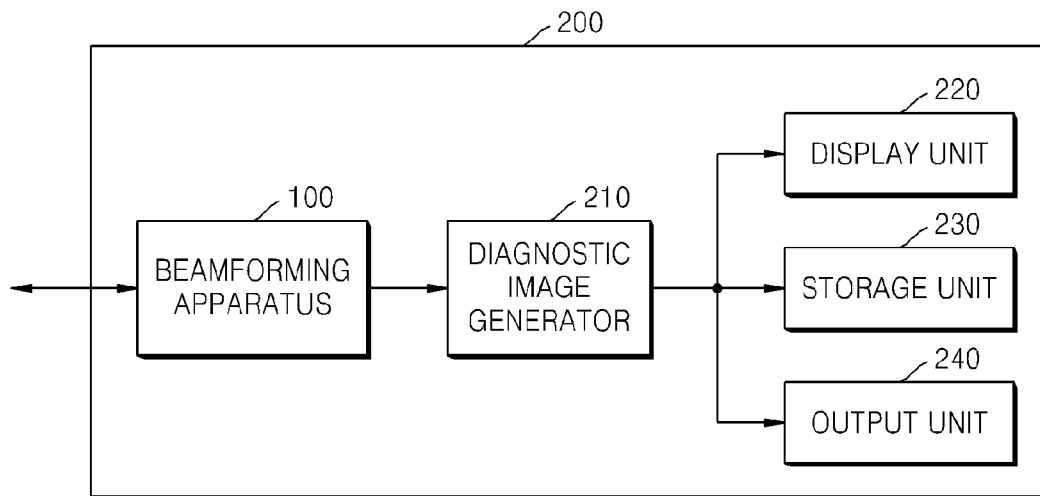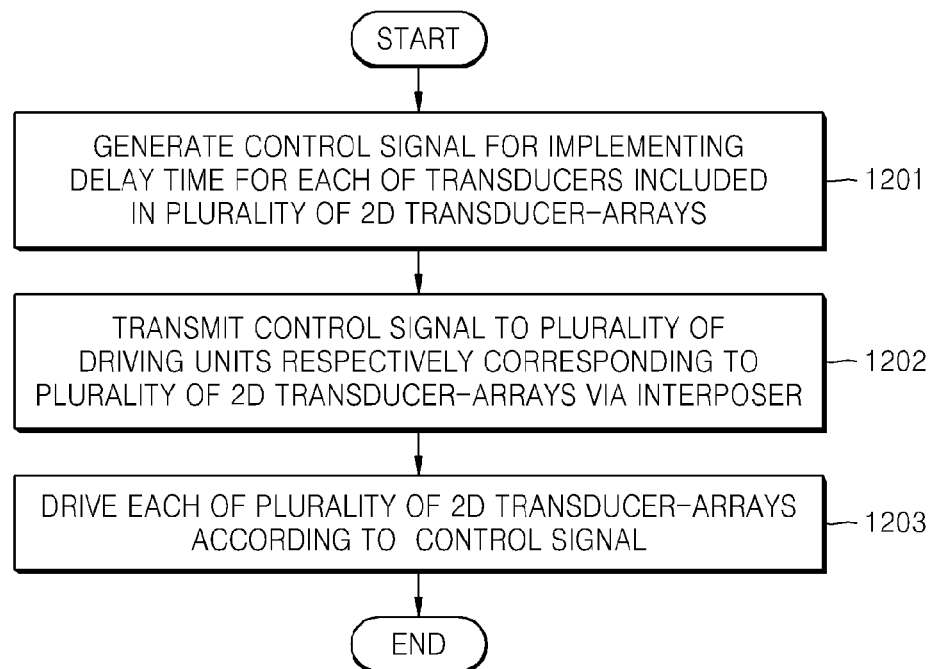
BEAMFORMING METHOD AND APPARATUS, AND MEDICAL IMAGING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of Korean Patent Application No. 10-2011-0039082 filed on Apr. 26, 2011, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field

This disclosure relates to a beamforming method and apparatus, and a medical imaging system therefor.

2. Description of the Related Art

A two-dimensional (2D) transducer-array is an array of p×q transducers, and is used for multi-channel beamforming to obtain a high-definition three-dimensional (3D) image. Beamforming methods may be generally classified into digital beamforming, in which all channels are processed in a digital manner, analog beamforming, in which all channels are processed in an analog manner, and hybrid beamforming, that is, a combination of digital beamforming and analog beamforming.

SUMMARY

According to an aspect, a beamforming apparatus includes a plurality of two-dimensional (2D) transducer-arrays each including a plurality of transducers; an interposer configured to electrically connect the plurality of 2D transducer-arrays to each other; a controller configured to generate a control signal for implementing a delay time for each of the transducers of each of the plurality of 2D transducer-arrays; and output the control signal to the interposer; and a plurality of driving units respectively corresponding to the plurality of 2D transducer-arrays, each driving unit of the plurality of driving units being configured to receive the control signal from the interposer; and drive a corresponding 2D transducer-array of the plurality of 2D transducer-arrays according to the control signal.

Each 2D transducer-array of the plurality of 2D transducer-arrays may have a structure enabling the plurality of 2D transducer-arrays to be arranged in a form of tiles; each driving unit of the plurality of driving units may be disposed below a corresponding 2D transducer-array of the plurality of 2D transducer-arrays, and may have a size enabling the plurality of 2D transducer-arrays to be arranged in the form of tiles; and the plurality of 2D transducer-arrays may be arranged in the form of tiles.

Each driving unit of the plurality of driving units may include a plurality of delayers respectively corresponding to the plurality of transducers of a corresponding 2D transducer-array of the plurality of 2D transducer-arrays; and each delayer of the plurality of delayers may be configured to delay a signal to be transmitted from a corresponding transducer of the plurality of transducers; and delay a signal received by the corresponding transducer of the plurality of transducers.

The plurality of 2D transducer-arrays may be arranged so that the plurality of transducers of the plurality of 2D transducer-arrays are arranged in rows of transducers and columns of transducers; each delayer of the plurality of delayers may include a plurality of delay lines configured to implement a transmitting delay time and a receiving delay time equal to the transmitting delay time for the corresponding transducer

according to the control signal; and the controller may generate the control signal to implement a same transmitting delay time and a same receiving delay time for the transducers in one row of transducers or the transducers in one column of transducers to perform analog beamforming.

The plurality of delay lines may include N sequentially arranged delay lines configured to implement a delay time of 0 up to a minimum delay time period to the power of N, wherein N is an integer equal to or greater than '0'.

Each delayer of the plurality of delayers may further include a plurality of switch devices respectively corresponding to the plurality of delay lines and each of the plurality of switch devices disposed at input terminal of corresponding delay line of the plurality of delay lines; each switch device of the plurality of switch devices may be configured to selectively use or not use a corresponding delay line of the plurality of delay lines in implementing the transmitting delay time and the receiving delay time according to the control signal; the controller may generate the control signal to control the switch devices; and the interposer may transmit the control signal to the switch devices.

Each driving unit of the plurality of driving units may further include a plurality of switch devices corresponding to the plurality of delayers; and each switch device of the plurality of switch devices may be connected to an output terminal of a corresponding delayer of the plurality of delayers, and may be configured to switch a delayed signal output from the corresponding delayer to a first output of the switch device if the delayed signal is the delayed signal to be transmitted; and switch the delayed signal output from the corresponding delayer to a second output of the switch device if the delayed signal is the delayed received signal.

The plurality of 2D transducer-arrays may be arranged so that the plurality of transducers of the plurality of 2D transducer-arrays are arranged in a horizontal direction and a vertical direction; and the apparatus may be configured to perform analog beamforming in the horizontal direction and digital beamforming in the vertical direction, or to perform digital beamforming in the horizontal direction and analog beamforming in the vertical direction.

The apparatus may include a digital beamformer configured to perform the digital beamforming on results outputted from the plurality of driving units representing a receiving beam formed by performing the analog beamforming.

The controller may be configured to generate a control signal to implement a same delay time for digital beamforming for transducers disposed in the direction in which the analog beamforming is performed, and a control signal to implement a same delay time for analog beamforming for transducers disposed in the direction in which digital beamforming is performed.

The interposer may include a synthesizer configured to synthesize signals synthesized and outputted from the plurality of driving units.

Each 2D transducer-array of the plurality of 2D transducer-arrays may be a capacitive micromachined ultrasonic transducer (cMUT); and each driving unit of the plurality of driving units may be an application specific integrated circuit (ASIC).

According to an aspect, a medical imaging system may include a beamforming apparatus configured to generate a control signal for implementing a delay time for each of a plurality of transducers of a plurality of two-dimensional (2D) transducer-arrays; transmit the control signal to a plurality of driving units respectively corresponding to the plurality of 2D transducer-arrays via an interposer that electrically connects the plurality of 2D transducer-arrays to each

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other; and drive each 2D transducer-array of the plurality of 2D transducer-arrays with a corresponding driving unit of the plurality of driving units according to the control signal transmitted via the interposer to form a receiving beam; and a diagnostic image generator configured to generate a diagnostic image using the receiving beam formed by the beamforming apparatus.

Each 2D transducer-array of the plurality of 2D transducer-arrays may have a structure enabling the plurality of 2D transducer-arrays to be arranged in a form of tiles; each driving unit of the plurality of driving units may be disposed below a corresponding 2D transducer-array of the plurality of 2D transducer-arrays, and may have a size enabling the plurality of 2D transducer-arrays to be arranged in the form of tiles; and the plurality of 2D transducer-arrays may be arranged in the form of tiles.

Each driving unit of the plurality of driving units may include a plurality of delayers respectively corresponding to the plurality of transducers of a corresponding 2D transducer-array of the plurality of 2D transducer-arrays; and each delayer of the plurality of delayers may be configured to delay a signal to be transmitted from a corresponding transducer of the plurality of transducers; and delay a signal received by the corresponding transducer of the plurality of transducers.

According to an aspect, a beamforming method includes generating a control signal for implementing a delay time for each of a plurality of transducers of each of a plurality of two-dimensional (2D) transducer-arrays; transmitting the control signal to a plurality of driving units respectively corresponding to the plurality of 2D transducer-arrays via an interposer that electrically connects the plurality of 2D transducer-arrays to each other; and driving each 2D transducer-array of the plurality of 2D transducer-arrays with a corresponding driving unit of the plurality of driving units according to the control signal transmitted via the interposer.

Each driving unit of the plurality of driving units may include a plurality of delayers respectively corresponding to the plurality of transducers of a corresponding 2D transducer-array of the plurality of 2D transducer-arrays; and the driving of each 2D transducer-array of the plurality of 2D transducer-arrays may include delaying a signal to be transmitted from each of the transducers with a corresponding delayer of the plurality of delayers; and delaying a signal received by each of the transducers with the corresponding delayer.

Each delayer of the plurality of delayers may include a plurality of delay lines configured to implement a transmitting delay time and a receiving delay time for a corresponding transducer of the plurality of transducers according to the control signal; and a plurality of switch devices respectively corresponding to the plurality of delay lines and each of the plurality of switch devices disposed at input terminal of corresponding delay line of the plurality of delay lines; and each switch device of the plurality of switch devices may be configured to selectively use or not use a corresponding delay line of the plurality of delay lines in implementing the transmitting delay time and the receiving delay time according to the control signal.

The plurality of 2D transducer-arrays may be arranged so that the plurality of transducers of the plurality of 2D transducer-arrays are arranged in a horizontal direction and a vertical direction; and the method may further include performing analog beamforming in the horizontal direction and digital beamforming in the vertical direction, or performing digital beamforming in the horizontal direction and analog beamforming in the vertical direction.

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According to an aspect, a non-transitory computer-readable storage medium stores a computer program for controlling a processor to perform the method described above.

Additional aspects will be set forth in part in the description that follows and, in part, will be apparent from the description, or may be learned by practice of the described examples.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and/or other aspects will become apparent and more readily appreciated from the following description of examples, taken in conjunction with the accompanying drawings of which:

FIG. 1 illustrates a beamforming apparatus according to an example of the invention;

FIG. 2 illustrates an arrangement of a plurality of two-dimensional (2D) transducer-arrays, and an arrangement of the plurality of 2D transducer-arrays and a plurality of driving units, according to an example of the invention;

FIG. 3 illustrates a beamforming apparatus according to an example of the invention;

FIG. 4 illustrates a first column of a first driver of FIG. 3;

FIG. 5 illustrates a delayer of FIG. 4;

FIG. 6 illustrates a process of transmitting a signal to a subject performed by a beamforming apparatus according to an example of the invention;

FIG. 7 illustrates a process of processing a signal reflected from a subject performed by a beamforming apparatus according to an example of the invention;

FIG. 8 is a block diagram of a beamforming apparatus according to an example of the invention;

FIG. 9 illustrates a process of forming a transmitting beam according to hybrid beamforming performed by a beamforming apparatus according to an example of the invention;

FIG. 10 illustrates a process of forming a receiving beam according to hybrid beamforming performed by a beamforming apparatus according to an example of the invention;

FIG. 11 is a block diagram of a medical imaging system according to an example of the invention; and

FIG. 12 is a flowchart illustrating a beamforming method according to an example of the invention.

DETAILED DESCRIPTION

Reference will now be made in detail to examples that are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout. In this regard, the examples may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the examples are merely described with reference to the figures to explain aspects of this description.

FIG. 1 illustrates a beamforming apparatus 100 according to an example of the invention. Referring to FIG. 1, the beamforming apparatus 100 includes a plurality of two-dimensional (2D) transducer-arrays 110, an interposer 120, a controller 130, and a plurality of driving units 140.

For convenience of explanation, FIG. 1 illustrates only elements of the beamforming apparatus 100 that are related to this example. It will be apparent to those of ordinary skill in the art that the beamforming apparatus 100 may also include elements other than those illustrated in FIG. 1.

The controller 130 and the plurality of driving units 140 may correspond to at least one processor. The at least one processor may be either an array of a plurality of logic gates or a combination of a general-purpose microprocessor and a memory storing a program that may be executed by the pro-

cessor. Otherwise, the at least one processor may be implemented by different types of hardware.

The beamforming apparatus **100** forms a transmitting beam, transmits the transmitting beam to a subject, receives a signal reflected from the subject, and forms a receiving beam from the received signal.

The beamforming apparatus **100** may output a signal containing information regarding the subject, and the signal may be displayed as a diagnostic image so that a user may view it. In this example, the diagnostic image may be a three-dimensional (3D) image, but is not limited thereto.

The beamforming apparatus **100** may perform only analog beamforming with respect to all channels, or may perform hybrid beamforming, that is, a combination of analog beamforming and digital beamforming. For convenience of explanation, it is hereinafter assumed that the beamforming apparatus **100** performs only analog beamforming. Cases where a beamforming apparatus **100** performs hybrid beamforming will be described in detail later with reference to FIGS. **8** to **10**.

The plurality of 2D transducer-arrays **110** transmit signals to and receive signals from a subject. The signals transmitted and received may be ultrasonic signals but are not limited thereto. In this example, the plurality of 2D transducer-arrays **110** include a first 2D transducer-array **111**, a second 2D transducer-array **112**, a third 2D transducer-array **113**, . . . through an m-th 2D transducer-array (not identified in FIG. **1**).

Each of the first 2D transducer-array **111** through the m-th 2D transducer-arrays has the same structure, so this example will be described focusing on the first 2D transducer-array **111**. Thus, descriptions below are also applicable to the second 2D transducer-array **112** through the m-th 2D transducer-array.

The first 2D transducer-array **111** includes pxq transducers. Each of the pxq transducers transforms an electrical signal into an ultrasonic signal, transmits the ultrasonic signal to a subject, and transforms an ultrasonic signal reflected from the subject into an electrical signal. However, this example is not limited to ultrasonic signals, and transducers for other type of signals may be used.

In this example, the first 2D transducer-array **111** may be a capacitive Micromachined Ultrasonic Transducer (cMUT) but is not limited thereto. The cMUT may be manufactured using Micro Electro Mechanical Systems (MEMS) techniques. By using the cMUT, multi-channel integration may be easily performed using a 2D array, and a high-definition image may be obtained by performing beamforming using the cMUT.

The plurality of 2D transducer-arrays **110** may have, for example, a structure in which a plurality of the first 2D transducer-arrays **111** are arranged. That is, the plurality of 2D transducer-arrays **110** may be structured by arranging the first 2D transducer-array **111** through the m-th 2D transducer-array in the form of tiles.

For example, KxL 2D transducer-array each including pxq transducers may be arranged in the form of tiles, and thus the plurality of 2D transducer-arrays **110** may include PxQ transducers. Here, p, q, K, and L each denote an integer equal to or greater than '1', P may be defined as 'pxK', and Q may be defined as 'qxL'. The arrangement of the plurality of 2D transducer-arrays **110** according to this example will be described in detail later with reference to FIG. **2**.

As described above, it is possible to construct the plurality of 2D transducer-arrays **110** to have a shape corresponding to a user environment by arranging a desired number of 2D transducer-arrays in a desired shape. Accordingly, an integra-

tion degree and expandability of the plurality of 2D transducer-arrays **110** may be improved.

The interposer **120** electrically connects the plurality of 2D transducer-arrays **110** to each other. For example, the first 2D transducer-array **111**, the second 2D transducer-array **112**, the third 2D transducer-array **113**, . . . through the m-th 2D transducer-array included in the plurality of 2D transducer-arrays **110** are electrically connected to each other via the interposer **120**.

In this example, electrically connecting of the plurality of 2D transducer-arrays **110** to each other via the interposer **120** enables the plurality of 2D transducer-arrays **110** to be controlled using the interposer **120**. In other words, each of transducers included in the plurality of 2D transducer-arrays **110** may be controlled to be respectively driven according to a predetermined delay time by using the interposer **120**.

In this example, the interposer **120** is connected to all of the transducers included in the plurality of 2D transducer-arrays **110**, and the plurality of 2D transducer-arrays **110** may thus be controlled via the interposer **120**.

The controller **130** generates a control signal for implementing a delay time for each of a plurality of transducers included in the plurality of 2D transducer-arrays **110**. The controller **130** also controls overall operations of the beamforming apparatus **100**. The controller **130** according to this example may be a main board included in the beamforming apparatus **100**.

In this example, the delay time is a delay time value for performing analog beamforming and may be calculated based on distances between a focusing point on a subject and each of the plurality of transducers included in the plurality of 2D transducer-arrays **110**, but is not limited thereto.

A method of calculating a delay time for performing analog beamforming will be apparent to those of ordinary skill in the art, and thus will not be described here.

Each of the plurality of driving units **140** corresponds to a respective one of the plurality of 2D transducer-arrays **110**, and drives the respective one of the plurality of 2D transducer-arrays **110** according to a control signal received via the interposer **120**. The plurality of driving units **140** may include a first driver **141**, a second driver **142**, a third driver **143**, . . . through an m-th driver (not identified in FIG. **1**).

In this example, each of the plurality of driving units **140** corresponds to a respective one of the plurality of 2D transducer-arrays **110**. For example, the first driver **141** corresponds to the first 2D transducer-array **111**, and drives the transducers of the first 2D transducer-array **111** via the interposer **120**.

As another example, the second driver **142** corresponds to the second 2D transducer-array **112**, and drives the transducers of the second 2D transducer-array **112** via the interposer **120**.

As described above, each of the plurality of driving units **140** corresponds to a respective one of the plurality of 2D transducer-arrays **110**, and drives the respective one of the plurality of 2D transducer-arrays **110** through the interposer **120**.

Since the first driver **141** through the m-th driver have the same structure, this example will be described focusing on the first driver **141**. Thus, the descriptions below are also applicable to the second driver **142** through the m-th driver.

In this example, the first driver **141** is disposed below the corresponding first 2D transducer-array **111**, and a size of the first driver **141** is determined so that the first 2D transducer-array **111** through the m-th 2D transducer-array may be arranged in the form of tiles.

However, instead of the first driver **141** being disposed below the corresponding first 2D transducer-array **111**, the interposer **120** may be disposed below the first driver **141** and the first 2D transducer-array **111** may be disposed below the interposer **120**. The structures of the first driver **141** and the corresponding first 2D transducer-array **111** will be described in detail later with reference to FIG. **2**.

When the size of the first driver **141** is determined so that the first 2D transducer-array **111** through the m-th 2D transducer-array may be arranged in the form of tiles, the first driver **141** is not larger than the first 2D transducer-array **111**.

For example, the size of the first driver **141** may be equal to or smaller than the size of the first 2D transducer-array **111**. Thus, the plurality of 2D transducer-arrays **110** may be constructed by continuously arranging the first 2D transducer-array **111** through the m-th 2D transducer-array in the form of tiles.

Thus, if the plurality of 2D transducer-arrays **110** according to this example are used, an aperture shape may be appropriately set according to a user environment, thereby improving the integration degree and the expandability of the beamforming apparatus **100**.

The first driver **141** according to this example may be an Application Specific Integrated Circuit (ASIC), but is not limited thereto.

As described above, the drivers **141** of the plurality of driving units **140** may drive respective ones of the plurality of 2D transducer-arrays **110**, and the plurality of 2D transducer-arrays **110** are electrically connected to each other via the interposer **120**. Therefore, the integration degree and expandability of the beamforming apparatus **100** may be improved, and channel expansion may be performed using beamforming in a simple manner.

FIG. **2** illustrates an arrangement **21** of the plurality of 2D transducer-arrays **110**, and an arrangement **22** of the plurality of 2D transducer-arrays **110** and the plurality of driving units **140**, according to an example of the invention.

In the plurality of 2D transducer-arrays **110**, a plurality of first 2D transducer-arrays **111** each including p×q transducers are arranged in the form of tiles. For example, K×L first 2D transducer-arrays **111** are arranged in the form of tiles and the plurality of 2D transducer-arrays **110** thus include P×Q transducers. Here, p, q, K, and L each denote an integer equal to or greater than '1', P may be defined as 'p×K', and Q may be defined as 'q×L'.

The arrangement **22** of the plurality of 2D transducer-arrays **110** and the plurality of driving units **140** is a cross-sectional view of a stacked structure of the plurality of 2D transducer-arrays **110**, an interposer **120**, and the plurality of driving units **140**. In the arrangement **22**, the plurality of driving units **140** are disposed below the plurality of 2D transducer-arrays **110**, and the interposer **120** is disposed between the plurality of 2D transducer-arrays **110** and the plurality of driving units **140** so as to connect the plurality of 2D transducer-arrays **110** and the plurality of driving units **140** to each other.

As illustrated in FIG. **2**, a size of each of the plurality of driving units **140** is equal or similar to a size of a corresponding 2D transducer-array included in the plurality of 2D transducer-arrays **110**. Thus, the plurality of 2D transducer-arrays **110** may be constructed by continuously arranging each of the plurality of 2D transducer-arrays **110** in the form of tiles, thereby improving expandability of a beamforming apparatus **100** according to an embodiment of the invention.

FIG. **3** illustrates a beamforming apparatus **100** according to an example of the invention. Referring to FIG. **3**, the beamforming apparatus **100** includes a plurality of 2D trans-

ducer-arrays **110**, an interposer **120**, a controller **130**, and a plurality of driving units **140**. For convenience of explanation, FIG. **3** illustrates that a first 2D transducer-array **111** included in the plurality of 2D transducer-arrays **110** includes p×q transducers.

The plurality of 2D transducer-arrays **110** include the first 2D transducer-array **111**, a second 2D transducer-array **112**, a third 2D transducer-array **113**, . . . through an m-th 2D transducer-array **114**. The first 2D transducer-array **111** includes a (1,1) transducer **111a**, a (1,2) transducer **111b**, a (1,3) transducer **111c**, a (1,q) transducer **111d**, a (p,q) transducer **111e**, and so on. The interposer **120** includes a synthesizer **121** and a signal transfer unit **122**. The plurality of driving units **140** include a first driver **141**, a second driver **142**, a third driver **143**, . . . through an m-th driver **144**. The first driver **141** includes a (1,1) driver **141a**, a (1,2) driver **141b**, a (1,3) driver **141c**, a (1,q) driver **141d**, a (p,q) driver **141e**, and so on. The first driver **141** also includes a synthesizer **1416a**, a synthesizer **1416b**, and a synthesizer **1416c**. Here, p, q, and m denote natural numbers.

FIG. **3** illustrates only elements of the beamforming apparatus **100** that are related to this example. It will be apparent to those of ordinary skill in the art that the beamforming apparatus **100** may also include elements other than those illustrated in FIG. **3**.

The beamforming apparatus **100** of FIG. **3** is another example of the beamforming apparatus **100** of FIG. **1**, and thus is not limited to the elements illustrated in FIG. **3**. The above descriptions relating to FIGS. **1** and **2** are also applicable to the beamforming apparatus **100** of FIG. **3**, and will not be repeated here.

The plurality of 2D transducer-arrays **110** include the first 2D transducer-array **111**, the second 2D transducer-array **112**, the third 2D transducer-array **113**, . . . through the m-th 2D transducer-array **114**. Each of the plurality of 2D transducer-arrays **110** includes a plurality of transducers.

For example, the first 2D transducer-array **111** includes the (1,1) transducer **111a**, the (1,2) transducer **111b**, and so on. Here, (1,1) and (1,2) denote coordinates of the transducers of the first 2D transducer-array **111**.

For example, the (1,1) transducer **111a**, the (1,2) transducer **111b**, the (1,3) transducer **111c**, and the (1,q) transducer **111d** are transducers in a first column of the transducers of the first 2D transducer-array **111**.

As another example, the (1,1) transducer **111a**, a (2,1) transducer **111f**, and a (p,1) transducer **111g** are transducers in a first row of the transducers of the first 2D transducer-array **111**.

For convenience of explanation, this example will now be described with respect to the columns of the first 2D transducer-array **111**, but this example is not limited thereto, and may be described with respect to the rows of the first 2D transducer-array **111**.

In this example, each of the first 2D transducer-array **111** through the m-th 2D transducer-array **114** transmits and receives signals to and from a subject using the transducers therein.

The interposer **120** electrically connects the plurality of 2D transducer-arrays **110** to each other. In greater detail, the first 2D transducer-array **111** through the m-th 2D transducer-array **114** in the plurality of 2D transducer-arrays **110** are electrically connected to each other via the interposer **120**.

The synthesizer **121** synthesizes signals synthesized and outputted from each of the plurality of driving units **140**. For example, the synthesizer **121** synthesizes signals received from each of the plurality of driving units **140**, i.e., the first driver **141** through the m-th driver **144**, and then outputs an

analog signal. In greater detail, the synthesizer **121** synthesizes signals received from, for example, transducers in one column of the transducers of the plurality of 2D transducer-arrays **110**.

In this case, the synthesizer **121** may sum signals generated in each of the columns of the first driver **141** through the m-th driver **144**, and may output an analog signal for each column. It will be apparent to those of ordinary skill in the art that the analog signal output from the synthesizer **121** may represent a receiving beam formed by performing analog beamforming.

The interposer **120** may further include an additional synthesizer (not shown) that sums signals received from the synthesizer **121**. For example, if each of the plurality of 2D transducer-arrays **110** includes transducers in three columns, the synthesizer **121** may sum signals received from the transducers in each of the three columns and the additional synthesizer may synthesize signals received from the synthesizer **121**.

The signal transfer unit **122** transmits signals exchanged between the plurality of 2D transducer-arrays **110**, the controller **130**, and the plurality of driving units **140**.

The controller **130** generates a control signal for implementing a delay time for each of the transducers included in the plurality of 2D transducer-arrays **110**.

Each of the plurality of driving units **140** corresponds to a respective one of the plurality of 2D transducer-arrays **110**, and drives the respective one of the plurality of 2D transducer-arrays **110** according to a control signal received via the interposer **120**.

As illustrated in FIG. **3**, the total number of the drivers of the plurality of driving units **140** is equal to the total number of the transducers of the plurality of 2D transducer-arrays **110**.

For example, if the plurality of 2D transducer-arrays **110** include two 2×4 2D transducer-arrays arranged in the form of tiles, the plurality of driving units **140** include drivers **141** and **142**, and each of the first and second drivers **141** and **142** includes eight drivers.

Thus, the (1,1) driver **141***a* of the first driver **141** drives the (1,1) transducer **111***a* of the first 2D transducer-array **111**, and the (1,2) driver **141***b* of the first driver **141** drives the (1,2) transducer **111***b* of the first 2D transducer-array **111**. In this way, each of the drivers of the plurality of driving units **140** a respective one of the transducers of the plurality of 2D transducer-arrays **110**.

In the beamforming apparatus **100** according to this example, a delay time for analog beamforming for each of transducers in one row of the transducers included in the plurality of 2D transducer-arrays **110** is the same. For example, the (1,1) driver **141***a*, a (2,1) driver **141***f*, and a (p,1) driver **141***g* respectively drive the (1,1) transducer **111***a*, the (2,1) transducer **111***f*, and the (p,1) transducer **111***g* so that each of transducers in one row have the same delay time for performing analog beamforming. However, the invention is not limited thereto, and a delay time for analog beamforming with regard to a column direction may be implemented for each of the transducers as will be described in detail later with reference to FIGS. **5** and **6**.

This example has been described above with respect to a row of transducers of the transducers, but the invention is not limited thereto, and a delay time for analog beamforming for each of the transducers in one column of the transducers of the plurality of 2D transducer-arrays **110** may be the same.

Accordingly, it is possible to remarkably reduce a total number of control lines to be connected to the plurality of 2D

transducer-arrays **110** since the interposer **120** electrically connects the plurality of 2D transducer-arrays **110** to each other.

FIG. **4** illustrates a first column **1410** of the first driver **141** of FIG. **3**. Referring to FIG. **4**, the (1,1) driver **141***a* includes a delayer **1411**, a switch device **1412**, a signal generator **1413**, a transmitting/receiving switch unit **1414**, and a received signal processor **1415**.

These elements of the (1,1) driver **141***a* are also included in each of the (1,2) driver **141***b* to the (1,q) driver **141***d* of the first column **1410**.

For convenience of illustration, FIG. **4** illustrates only the first driver **141**, but the second driver **142** through the m-th driver **144** also have the same structure as the first driver **141**.

The delayer **1411** delays a signal to be transmitted from and a signal received by a respective transducer of the transducers of the plurality of 2D transducer-arrays **110**. In greater detail, the delayer **1411** receives a control signal generated by the controller **130** via the interposer **120**, and delays a signal input to the delayer **1411** according to the control signal.

The signal input to the delayer **1411** may be either a pulse signal to be transmitted to be transmitted to a subject received from the controller **130** via the interposer **120**, or an echo signal reflected from the subject and received from the (1,1) transducer **111***a* of the plurality of 2D transducer-arrays **110** via the interposer **120**.

For example, the delayer **1411** according to this example may include a plurality of delay lines for implementing a transmitting delay time and a receiving delay time according to the control signal, and wherein delayers for transducers in one row of the transducers of the plurality of 2D transducer-arrays **110** are set to have the same delay time for analog beamforming, or delayers for transducers in one column of the transducers of the plurality of 2D transducer-arrays **110** are set to have the same delay time for analog beamforming.

In this case, the transmitting delay time and the receiving delay time for each of the transducers of the plurality of 2D transducer-arrays **110** are the same. In greater detail, with regard to each of the transducers, a delay time applied to a signal to be transmitted and a delay time applied to a signal that has been received are the same. Thus, the beamforming apparatus **100** of FIG. **3** may process transmitting and receiving of signals in an analog manner as will be described in detail later with reference to FIG. **5**.

The switch device **1412** is connected to an output terminal of the delayer **1411**. The switch device **1412** according to this example may be any of various devices for performing switching that are known in the art.

The switch device **1412** performs switching according to whether a signal output from the delayer **1411** is to be transmitted to a subject or has been reflected from the subject.

If the signal output from the delayer **1411** is to be transmitted to the subject, the switch device **1412** performs switching to transmit the signal output from the delayer **1411** to the signal generator **1413**.

If the signal output from the delayer **1411** has been reflected from the subject, the switch device **1412** performs switching to transmit the signal output from the delayer **1411** to the synthesizer **1416***a*.

Thus, the plurality of driving units **140** control a transmitting operation and a receiving operation for each of the transducers of the plurality of 2D transducer-arrays **110** by using the switch device **1412** connected to the output terminal of the delayer **1411**.

Thus, the plurality of driving units **140** control a transmitting operation and a receiving operation for each of the transducers of the plurality of 2D transducer-arrays **110** by using

the same circuit, thereby reducing manufacturing costs and circuit complexity of the beamforming apparatus **100**.

The signal generator **1413** generates a pulse signal to be transmitted from the plurality of 2D transducer-arrays **110** to the subject. That is, the signal generator **1413** generates a pulse signal corresponding to the signal output from the delayer **1411**.

For example, the signal generator **1413** according to this example may be an ultrasonic transmission pulse signal generator that generates an ultrasonic pulse transmission signal to be transmitted to the subject, but is not limited thereto.

The transmitting/receiving switch unit **1414** performs switching according to whether a signal input thereto has been generated by the signal generator **1413** or has been reflected from the subject and received from the (1,1) transducer **111***a* of the plurality of 2D transducer-arrays **110** in FIG. 3 via the interposer **120**.

If the input signal has been generated by the signal generator **1413**, the transmitting/receiving switch unit **1414** performs switching to transmit the input signal to the interposer **120**. In addition, the transmitting/receiving switch unit **1414** may also perform switching to transmit signals according to each of a plurality of channels.

Thus, the input signal generated by the signal generator **1413** is transmitted to the (1,1) transducer **111***a* of the plurality of 2D transducer-arrays **110** via the interposer **120**, and the (1,1) transducer **111***a* of the plurality of 2D transducer-arrays **110** transmits this signal to the subject.

If the input signal has been reflected from the subject and received from the (1,1) transducer **111***a* of the plurality of 2D transducer-arrays **110** via the interposer **120**, the transmitting/ receiving switch unit **1414** performs switching to transmit the input signal to the received signal processor **1415**. The transmitting/receiving switch unit **1414** may also perform switching to receive signals according to each of a plurality of channels.

The received signal processor **1415** performs a predetermined processing on a signal received from the transmitting/ receiving switch unit **1414**. For example, although not shown, the received signal processor **1415** may include a low-noise amplifier (LNA) that reduces noise from an analog signal reflected from the subject, a variable gain amplifier (VGA) that controls a gain according to an input signal, a preamplifier, or any combination thereof. In this case, the VGA may be a time gain compensator (TGC) that compensates for a gain according to a distance from the subject to a focusing point, but is not limited thereto. The TGC is well known in the art, and thus will not be described in detail here.

The synthesizer **1416***a* synthesizes signals respectively generated by the (1,1) driver **141***a*, the (1,2) driver **141***b*, the (1,3) driver **141***c*, and the (1,q) driver **141***d*. Thus, the synthesizer **1416***a* sums signals generated by the drivers in the first column **1410** of the first driver **141** and then outputs an analog signal. The analog signal output from the synthesizer **1416***a* may represent a receiving beam obtained through analog beamforming.

A case where the (1,1) driver **141***a* transmits a signal to a subject will be described. A pulse signal generated by the controller **130** is input to the delayer **1411** via the interposer **120**, delayed by the delayer **1411** for a predetermined transmission delay time, and then input to the signal generator **1413** via the switch device **1412**. Then, an ultrasonic transmission pulse signal generated by the signal generator **1413** in response to the input signal is sequentially transmitted to the transmitting/receiving switch unit **1414**, the interposer **120**, the (1,1) transducer **111***a*, and finally to the subject.

A case where the (1,1) driver **141***a* processes a signal reflected from the subject will be described. A reflected signal input to the (1,1) transducer **111***a* is transmitted to the received signal processor **1415** via the interposer **120** and the transmitting/receiving switch unit **1414**, processed by the received signal processor **1415** in a predetermined manner, input to the delayer **1411**, delayed by the delayer **1411** for a predetermined receiving delay time equal to a transmission delay time, and then finally input to the synthesizer **1416***a* via the switch device **1412**.

Then, the synthesizer **1416***a* synthesizes signals received from transducers in the first column of the transducers of the first 2D transducer-array **111**, and transmits resultant signals of the synthesizing to the synthesizer **121** of the interposer **120**. The synthesizer **121** of the interposer **120** synthesizes signals received from drivers in first columns of the drivers of the first driver **141** through the m-th driver **144** and then outputs a resultant signal. Thus, the synthesizer **121** of the interposer **120** synthesizes signals received from transducers in a first column of the transducers of the plurality of 2D transducer-arrays **110** to obtain one analog signal.

The interposer **120** may further include an additional synthesizer (not shown) that synthesizes results of synthesizing signals generated from the transducers in each of columns of the plurality of 2D transducer-arrays **110**. The additional synthesizer and the synthesizer **121** may be combined together to form one synthesizer.

Accordingly, the beamforming apparatus **100** may efficiently control the plurality of 2D transducer-arrays **110**, and thus may rapidly and precisely perform beamforming.

FIG. 5 illustrates the delayer **1411** of FIG. 4. Referring to FIG. 5, the delayer **1411** includes a plurality of delay lines **510** to **517** for delaying a signal to be transmitted from and a signal received by one of the transducers of the plurality of 2D transducer-arrays **110** according to a control signal, and a plurality of switch devices **500** to **507**. The plurality of delay lines **510** to **517** may be analog delay line circuits that produce an analog signal delay.

For convenience of explanation, FIG. 5 illustrates a case where a delay time of 0 ns to 255 ns is implemented in units of 1 ns by using eight delay lines and eight switch devices, but the invention is not limited thereto.

Referring to FIGS. 3 to 5, a signal IN1 input to the delayer **1411** may correspond to either a signal reflected from a subject and received from the received signal processor **1415**, or a signal received from the interposer **120** to be transmitted to the subject.

In FIG. 5, b0 to b7 input to the delayer **1411** are bits of a control signal generated by the controller **130** to implement the delay time for each of the transducers of the plurality of 2D transducer-arrays **110**, and are transmitted to the delayer **1411** via the interposer **120**.

The plurality of delay lines **510** to **517** are n sequentially arranged delay lines, where n is an integer greater than or equal to 0, and include a 0-th delay line **510** (n=0) to a seventh delay line **517** (n=7). Each of the plurality of delay lines **510** to **517** implements a delay time up to a minimum delay time period to a power of n (i.e., if the minimum delay time period is D, the delay time of n-th delay line is D"). If n=7 as in FIG. 5 and the minimum delay time period is 2 ns, then the delayer **1411** implements a delay time of 0 ns to 255 ns in units of 1 ns, but the invention is not limited thereto.

In greater detail, if the minimum delay time period is 2 ns, then the 0-th delay (n=0) line **510** produces a signal delay of $2^0=1$ ns, the first delay line **511** (n=1) produces a signal delay of $2^1=2$ ns, the second delay line **512** (n=2) produces a signal delay of $2^2=4$ ns, the third delay line **513** (n=4) produces a

signal delay of 2^3=8 ns, the fourth delay line **514** produces a signal delay of 2^4=16 ns, the fifth delay line **515** (n=5) produces a signal delay of 2^5=32 ns, the sixth delay line **516** (n=6) produces a signal delay of 2^6=64 ns, and the seventh delay line **517** (n=7) produces a signal delay of 2^7=128 ns. Thus, a maximum delay time that can be implemented by the delayer **1411** is 1 ns+2 ns+4 ns+8 ns+16 ns+32 ns+64 ns+128 ns=255 ns.

A method of delaying an input signal for a predetermined time by using the plurality of delay lines **510** to **517** will be apparent to those of ordinary skill in the art, and thus will not be described here.

The controller **130** generates the control signal having the bits b0 to b7, and the delayer **1411** delays an input signal for a predetermined time period according to the control signal having the bits b0 to b7.

More specifically, the delayer **1411** implements a delay time by using the plurality of switch devices **500** to **507** respectively disposed at input terminals of the plurality of delay lines **510** to **517**, the controller **130** generates the control signal having the control signal bits b0 to b7 for controlling the plurality of switch devices **500** to **507**, and the interposer **120** transmits the control signal having the bits b0 to b7 to the switch devices **500** to **507**.

For example, the bits b0 to b7 of the control signal respectively control the 0-th switch device **500** to the seventh switch device **507**. For convenience of explanation, it is will be assumed that the plurality of switch devices **500** to **507** perform switching to transmit signals input thereto to respective ones of the plurality of delay lines **510** to **517** when respective bits of the control signal generated by the controller **130** are '1', and perform switching to prevent the signals input thereto from being transmitted to the respective ones of the plurality of delay lines **510** to **517** when the respective bit of the control signal are '0', but the invention is not limited thereto.

The delay time implemented by the delayer **1411** according to the bits b0 to b7 of the control signal generated by the controller **130** may be as shown in the following Table 1:

TABLE 1

b0	b1	b2	b3	b4	b5	b6	b7	Delay Time
0	0	0	0	0	0	0	0	0 ns
1	0	0	0	0	0	0	0	1 ns
0	1	0	0	0	0	0	0	2 ns
1	1	0	0	0	0	0	0	3 ns
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
0	1	1	1	1	1	1	1	254 ns
1	1	1	1	1	1	1	1	255 ns

For example, referring to Table 1, if the controller **130** generates '0000000' as the bits b0 to b7 and inputs '0000000' to the delayer **1411**, the signal IN1 input to the delayer **1411** does not pass through any of the delay lines **510** to **517**, and is thus delayed for 0 ns and is then output. In this case, the input signal IN1 is not delayed and is directly output.

If the controller **130** generates '1000000' as the bits b0 to b7 and inputs '1000000' to the delayer **1411**, the input signal IN1 passes through only the 0-th delay line **510**, and is thus delayed for 1 ns and is then output.

If the controller **130** generates '1100000' as the bits b0 to b7 and inputs '1100000' to the delayer **1411**, the input signal IN1 passes through only the 0-th delay line **510** and the first delay line **511**, and is thus delayed for 3 ns and is then output.

Thus, the controller **130** may generate the bits b0 to b7 of the control signal to have any value from '0000000' to

'1111111', causing a signal input to the delayer **1411** to be delayed for a time period corresponding to the bits b0 to b7 of the control signal.

As described above, the delayer **1411** may implement various delay times by using the plurality of delay lines **510** to **517** and the plurality of switch devices **500** to **507**. Also, the delayer **1411** may be used to delay both a signal to be transmitted to a subject and a signal reflected from the subject, thereby simplifying a structure of the beamforming apparatus **100**.

FIG. **6** illustrates a process of transmitting a signal to a subject performed by a beamforming apparatus **100** according to an example of the invention.

Referring to FIGS. **4** and **6**, a first 2D transducer-array **111** is illustrated as including transducers in only two columns, but is not limited thereto, and may include transducers in a different number of columns.

Referring to FIG. **6**, each of a (1,1) driver **141**a to a (1,16) driver **142**h included in a plurality of driving units **140** includes the delayer **1411**, the switch device **1412**, the signal generator **1413**, the transmitting/receiving switch unit **1414**, and the received signal processor **1415** illustrated in FIG. **4**.

Thus, a pulse signal corresponding to an input signal generated by a controller **130** and a control signal having the bits b0 to b7 generated by the controller **130** (both the pulse signal and the control signal are shown as a single line in FIG. **6** for clarity) are input to the plurality of driving units **140** via a signal transfer unit **122** of an interposer **120**. Then, the plurality of driving units **140** process the pulse signal in a predetermined manner according to the control signal to drive each of the plurality of 2D transducer-arrays **110** to transmit an ultrasonic transmission pulse signal to a subject.

In this example, all of the transducers included in the plurality of 2D transducer-arrays **110** are electrically connected to each other by the interposer **120**. Thus, the pulse signal generated by the controller **130** is simultaneously input to the plurality of driving units **140** via the interposer **120**, and the ultrasonic transmission pulse signal output from the plurality of driving units **140** is supplied to the plurality of 2D transducer-arrays **110** via the interposer **120**. However, for increased clarity, the transmission pulse signal output from a (2,1) driver **141**i to a (2,16) driver in the plurality of driving units **140** are shown in FIG. **6** as being supplied to the plurality of 2D transducer-arrays **110** outside the interposer **120**, but they are actually supplied via the interposer **110**.

In this case, the plurality of driving units **140** drive the transducers of the plurality of 2D transducer-arrays **110** so that the transducers of the plurality of 2D transducer-arrays **110** transmit the ultrasonic transmission pulse signal to a subject at different times according to predetermined delay times.

In the first driver **141**, the (1,1) driver **141**a, the (1,2) driver **141**b, . . . and a (1,8) driver **141**h drive a (1,1) transducer **111**a, a (1,2) transducer **111**b, . . . and a (1,8) transducer **111**h included in the first 2D transducer-array **111**, respectively.

As described above, each of the plurality of driving units **140** drives the transducers of the plurality of 2D transducer-arrays **110**, respectively.

In this case, the (1,1) driver **141**a and a (2,1) driver **141**i drive the (1,1) transducer **111**a and the (2,1) transducer **111**i in such a manner that the (1,1) transducer **111**a and the (2,1) transducer **111**i may have the same delay time. Thus, since for analog beamforming in a vertical direction, the delay time for transducers disposed in a column-wise direction, i.e., a horizontal direction, are the same, it is possible to greatly reduce a total number of control lines to be connected to the plurality of 2D transducer-arrays **110** in the beamforming apparatus

100, and transmit an ultrasonic transmission pulse signal to a subject with a relatively small amount of calculation.

FIG. **7** illustrates a process of processing a signal reflected from a subject performed by a beamforming apparatus **100** according to an example of the invention.

Referring to FIGS. **4** and **7**, a first 2D transducer-array **111** is illustrated as including transducers in only two columns, but is not limited thereto, and may include transducers in a different number of columns.

Referring to FIG. **7**, each of a (1,1) driver **141***a* to a (1,16) driver **142***h* included in a plurality of driving units **140** includes the delayer **1411**, the switch device **1412**, the signal generator **1413**, the transmitting/receiving switch unit **1414**, and the received signal processor **1415** illustrated in FIG. **4**.

A synthesizer **1416***a* synthesizes signals reflected from a subject and received from transducers in a first column of the first 2D transducer-array **111**. A synthesizer **1416***b* synthesizes signals reflected from the subject and received from transducers in a second column of the first 2D transducer-array **111**. A synthesizer **1426***a* synthesizes signals reflected from the subject and received from transducers in a first column of a second 2D transducer-array **112**. A synthesizer **1426***b* synthesizes signals reflected from the subject and received from transducers in a second column of the second 2D transducer-array **112**. A synthesizer **121** of an interposer **120** synthesizes signals outputted from each of first and second drivers **141** and **142**.

Thus, the synthesizers **1416***a*, **1416***b*, **1426***a*, and **1426***b* included in the plurality of driving units **140** synthesize signals received from transducers in each of a plurality of columns of the plurality of 2D transducer-arrays **110**. The synthesizer **121** of the interposer **120** synthesizes signals outputted from the synthesizers **1416***a*, **1416***b*, **1426***a*, and **1426***b*, and outputs one output signal.

For example, if the plurality of 2D transducer-arrays **110** consist of a first column and a second column, the synthesizer **121** of the interposer **120** generates an output signal by synthesizing signals received from transducers in the first column, and generates another output signal by synthesizing signals received from transducers in the second column.

Also, although not shown in FIG. **7**, the interposer **120** may further include an additional synthesizer that synthesizes signals outputted from the synthesizer **121**.

Accordingly, in the beamforming apparatus **100**, a total number of control lines that are to be connected to the transducers of the plurality of 2D transducer-arrays **110** may be remarkably reduced, and a receiving beam may be formed containing information regarding a subject by using the beamforming apparatus **100** with a relatively small amount of calculation.

FIG. **8** is a block diagram of a beamforming apparatus **100** according to an example of the invention Referring to FIG. **8**, the beamforming apparatus **100** includes a plurality of 2D transducer-arrays **110**, an interposer **120**, a controller **130**, a plurality of driving units **140**, a digital beamformer **150**, and an analog-to-digital converter (ADC) **160**. The digital beamformer **150** includes a transmitting digital beamformer **152** and a receiving digital beamformer **154**.

FIG. **8** illustrates only elements of the beamforming apparatus **100** that are related to this example. It will be apparent to those of ordinary skill in the art that the beamforming apparatus **100** may also include elements other than those illustrated in FIG. **8**.

The beamforming apparatus **100** of FIG. **8** is another example of the beamforming apparatus **100** shown in FIG. **1**, **2**, or **3**, and is thus not limited to the elements illustrated in FIG. **8**. The above descriptions related to FIGS. **1** to **7** are also

applicable to the beamforming apparatus **100** of FIG. **8**, and thus will not be repeated here.

In the beamforming apparatus **100**, each of the plurality of 2D transducer-arrays **110** so that the transducers of the plurality of 2D transducer-arrays **110** are arranged in vertical and horizontal directions. Thus, the beamforming apparatus **100** may perform analog beamforming in one of the vertical and horizontal directions and may perform digital beamforming in the other one of the vertical and horizontal directions. Also, in the beamforming apparatus **100**, a same delay time for digital beamforming is applied to transducers arranged in a direction in which analog beamforming is performed, and a same delay time for analog beamforming is applied to transducers arranged in a direction in which digital beamforming is performed. This will be described in detail later with reference to FIGS. **9** and **10**.

Here, the horizontal direction is a column-wise direction in which the transducers of the plurality of 2D transducer-arrays **110** are arranged, and the vertical direction is a row-wise direction in which the transducers of the plurality of 2D transducer-arrays **110** are arranged.

The digital beamformer **150** performs digital beamforming. That is, the digital beamformer **150** forms a transmitting beam using the transmitting digital beamformer **152** and forms a receiving beam using the receiving digital beamformer **154**.

The transmitting digital beamformer **152** forms a transmitting beam by using a pulse signal corresponding to a signal that is to be transmitted in consideration of a delay time period according to a predetermined control signal. In this case, the pulse signal and the predetermined control signal may be transmitted to the transmitting digital beamformer **152** from the controller **130** via the interposer **120**.

Also, the receiving digital beamformer **154** synthesizes a plurality of digital signals outputted from an ADC **160** in consideration of a delay time period according to a predetermined control signal so as to generate a receiving beam containing information regarding a subject.

The ADC **160** converts analog signals outputted from the plurality of driving units **140** into digital signals.

Accordingly, the beamforming apparatus **100** may perform hybrid beamforming, that is, a combination of digital beamforming and analog beamforming. Thus, not only may an amount of calculation be reduced but also only a relatively small number of control lines are needed for the controller **130** to control the transducers, thereby simplifying manufacturing of the beamforming apparatus **100**.

FIG. **9** illustrates a process of forming a transmitting beam according to hybrid beamforming performed by a beamforming apparatus **100** according to an example of the invention. The beamforming apparatus **100** of FIG. **9** is the same as the beamforming apparatus **100** of FIG. **6**, except that a transmitting digital beamformer **152** has been added, and thus will be described by focusing on the differences between the beamforming apparatus **100** of FIG. **9** and the beamforming apparatus **100** of FIG. **6**.

The beamforming apparatus **100** of FIG. **6** forms a transmitting beam by performing only analog beamforming, whereas the beamforming apparatus **100** of FIG. **9** forms a transmitting beam by performing hybrid beamforming.

For convenience of explanation, it will be assumed that the beamforming apparatus **100** of FIG. **9** performs analog beamforming in a vertical direction and performs digital beamforming in a horizontal direction, but the invention is not limited thereto.

The transmitting digital beamformer **152** receives a pulse signal corresponding to a signal that is to be transmitted from

a controller **130**, and forms a transmitting beam in consideration of a delay time for performing digital beamforming according to a control signal generated by the controller **130**.

In this case, since the beamforming apparatus **100** performs digital beamforming in the horizontal direction, the same delay time for digital beamforming is applied to transducers disposed in a same column of the transducers included in the plurality of 2D transducer-arrays **110**.

For example, the same delay time for digital beamforming is applied to transducers **111a** to **111d** and **112a** to **112d** in a first column **91** of the plurality of 2D transducer-arrays **110**. Likewise, the same delay time for digital beamforming is applied to transducers **111i** to **111l** and **112i** to **112l** in a second column **92**, and the same delay time for digital beamforming is applied to transducers **111q** to **111t** and **112q** to **112t** in a third column **93**. However, different delay times are applied to the transducers **111a**, **111i**, and **111q** in one row.

That is, if the beamforming apparatus **100** performs digital beamforming in the horizontal direction, a delay time for digital beamforming applied to transducers disposed in a same column is the same.

Thus, the transmitting beam formed by the transmitting digital beamformer **152** by performing digital beamforming in the horizontal direction is transmitted to the plurality of driving units **140**, which form a transmitting beam by performing analog beamforming in the vertical direction.

In the plurality of driving units **140**, a first driver **141** forms a transmitting beam according to a delay time for analog beamforming for each of the transducers of a first 2D transducer-array **111**, and a second driver **142** forms a transmitting beam according to a delay time for analog beamforming for each of the transducers of a second 2D transducer-array **112**.

In this case, a different delay time for analog beamforming is applied to the transducers **111a** to **111d** and **112a** to **112d** in the first column **91**, and a same delay time for analog beamforming is applied to the transducers **111a**, **111i**, and **111q** in one row.

In other words, if the beamforming apparatus **100** performs analog beamforming in the vertical direction, a same delay time for analog beamforming is applied to transducers disposed in the same row.

Since an interposer **120** electrically connects the plurality of 2D transducer-arrays **110** to each other, a (1,1) driver **141a** may control the (1,1) transducer **111a**, a (2,1) driver **141i** may control the (2,1) transducer **111i**, and a (3,1) driver **141q** may control the (3,1) transducer **111q**. Also, a (1,2) driver **141b** may control the (1,2) transducer **111b**, a (2,2) driver **141j** may control a (2,2) transducer **111j**, and a (3,2) driver **141r** may control a (3,2) transducer **111r**. In this manner, each of the plurality of driving units **140** may control the transducers of corresponding one of the plurality of 2D transducer-arrays **110**.

As described above, a same delay time for analog beamforming is applied in the horizontal direction and a same delay time for digital beamforming is applied in the vertical direction. Accordingly, in the beamforming apparatus **100**, it is possible to greatly reduce a total number of control lines to be connected to a plurality of 2D transducer-arrays **110**, and perform hybrid beamforming.

FIG. **10** illustrates a process of forming a receiving beam according to hybrid beamforming performed by a beamforming apparatus **100** according to an example of the invention. The beamforming apparatus **100** of FIG. **10** is the same as the beamforming apparatus **100** of FIG. **7** except that an ADC **160** and a receiving digital beamformer **154** have been added, and thus will be described by focusing on the differences

between the beamforming apparatus **100** of FIG. **10** and the beamforming apparatus **100** of FIG. **7**.

The beamforming apparatus **100** of FIG. **7** forms a receiving beam by performing only analog beamforming, whereas the beamforming apparatus **100** of FIG. **10** forms a receiving beam by performing hybrid beamforming.

For convenience of explanation, it will be assumed that the beamforming apparatus **100** of FIG. **10** performs analog beamforming in a vertical direction and performs digital beamforming in a horizontal direction, but the invention is not limited thereto.

A synthesizer **121** of an interposer **120** generates analog output signals by forming receiving beams by performing analog beamforming on transducers in first to third columns **91** to **93** of a plurality of 2D transducer-arrays **110**.

The ADC **160** converts the analog output signals obtained by performing analog beamforming into digital output signals. The receiving digital beamformer **154** synthesizes the digital output signals and outputs one digital output signal.

In this case, a same delay time may be applied in a plurality of driving units **140** and the receiving digital beamformer **154** as in the process of forming a transmitting beam described above with reference to FIG. **9**.

That is, the same delay time for digital beamforming is applied to transducers **111a** to **111d** and **112a** to **112d** in a first column **91** of the plurality of 2D transducer-arrays **110**, and different delay times are applied to transducers **111a**, **111i**, and **111q** in one row.

Also, a different delay time for analog beamforming is applied to the transducers **111a** to **111d** and **112a** to **112d** in the first column **91**, and a same delay time for analog beamforming may be applied to the transducers **111a**, **111i**, and **111q** in one row.

In other words, if the beamforming apparatus **100** performs digital beamforming in the horizontal direction and analog beamforming in the vertical direction, a same delay time for digital beamforming is applied to transducers disposed in the same column, and a same delay time for analog beamforming is applied to transducers disposed in the same row.

Since the interposer **120** electrically connects the plurality of 2D transducer-arrays **110** to each other, a (1,1) driver **141a** may control the (1,1) transducer **111a**, a (2,1) driver **141i** may control the (2,1) transducer **111i**, and a (3,1) driver **141q** may control the (3,1) transducer **111q**. Also, a (1,2) driver **141b** may control the (1,2) transducer **111b**, a (2,2) driver **141j** may control a (2,2) transducer **111j**, and a (3,2) driver **141r** may control a (3,2) transducer **111r**. In this manner, each of the plurality of driving units **140** may control the transducers of a corresponding one of the plurality of 2D transducer-arrays **110**.

As described above, a same delay time for analog beamforming is applied in the horizontal direction and a same delay time for digital beamforming is applied in the vertical direction. Accordingly, in the beamforming apparatus **100** according to this example, it is possible to greatly reduce a total number of control lines to be connected to the plurality of 2D transducer-arrays **110** and perform hybrid beamforming.

FIG. **11** is a block diagram of a medical imaging system **200** according to an example of the invention. The medical imaging system **200** includes a beamforming apparatus **100**, a diagnostic image generator **210**, a display unit **220**, a storage unit **230**, and an output unit **240**.

For convenience of explanation, FIG. **11** illustrates only elements of the medical imaging system **200** that are related to this example. It will be apparent to those of ordinary skill in

the art that the medical imaging system **200** may also include elements other than the elements illustrated in FIG. **11**.

The beamforming apparatus **100** illustrated in FIG. **11** is an example of the beamforming apparatus **100** shown in FIG. **1**, **2**, **3**, or **8**. Thus, the descriptions related to FIGS. **1** to **10** are also applicable to the medical imaging system **200** of FIG. **11**, and thus will be repeated here.

In this example, the medical imaging system **200** provides a diagnostic image of a subject. For example, the medical imaging system **200** may display a diagnostic image of a subject or may output a signal representing the diagnostic image to an external device capable of displaying the diagnostic image.

Referring to FIGS. **1** and **11**, the beamforming apparatus **100** generates a control signal for implementing a delay time for each of transducers included in a plurality of 2D transducer-arrays **110**, transmits the control signal to a plurality of driving units **140** corresponding to the plurality of 2D transducer-arrays **110** via an interposer **120**, and drives each of the plurality of 2D transducer-arrays **110** according to the control signal received via the interposer **120**. The plurality of 2D transducer-arrays **110** are electrically connected to each other via the interposer **120**.

The diagnostic image generator **210** generates a diagnostic image from a receiving beam formed by the beamforming apparatus **100**. More specifically, the diagnostic image generator **210** may include a digital signal processor (DSP) (not shown) and a digital scan converter (DSC) (not shown). In this example, the DSP generates image data representing, for example, a brightness mode (B-mode), a color mode (C-mode), or a Doppler mode (D-mode) by processing a signal output from the beamforming apparatus **100** and/or a signal stored in the storage unit **230**. The DSC generates a scan-converted diagnostic image to display the image data generated by the DSP.

The display unit **220** displays the diagnostic image received from the diagnostic image generator **210**. For example, although not shown, the display unit **220** may include various output devices, such as a display panel, a liquid crystal display (LCD) screen, and a monitor, in the medical imaging system **200**.

However, it will be apparent to those of ordinary skill in the art that the medical imaging system **200** according to this example may not include the display unit **220** and the diagnostic image generated by the diagnostic image generator **210** may instead be output by the output unit **240** to an external display device (not shown).

The storage unit **230** stores data generated during an operation of the medical imaging system **200**. For example, the storage unit **230** may store, for example, the receiving beam formed by the beamforming apparatus **100**, the image data representing the b-mode, c-mode, or d-mode, or the scan-converted diagnostic image.

The storage unit **230** according to this example is a general storage medium, and it will be apparent to those of ordinary skill in the art that examples of the storage unit **230** include a hard disc drive (HDD), read only memory (ROM), random access memory (RAM), flash memory, a memory card, or any other suitable storage unit that is known in the art.

The output unit **240** may exchange data with an external device via a wired/wireless network or wired serial communication. In this case, the wired/wireless network may be the Internet, a local area network (LAN), a wireless LAN, a wide area network (WAN), or a personal area network (PAN), but is not limited thereto, and may be any type of a network via which information may be exchanged.

The storage unit **230** and the output unit **240** according to this example may be manufactured in a single body providing other operations, such as image interpretation and image searching, to form a picture archiving and communication system (PACS).

FIG. **12** is a flowchart illustrating a beamforming method according to an example of the invention. Referring to FIG. **12**, the method includes operations sequentially performed in the beamforming apparatus **100** shown in FIG. **1**, **2**, **3**, or **8** or the medical imaging system **200** of FIG. **11**. Thus, although not described here, the above descriptions related to the beamforming apparatuses **100** shown in FIGS. **1**, **2**, **3**, and **8** and the medical imaging system **200** of FIG. **11** may also be applied to the beamforming method of FIG. **12**.

Referring to FIG. **12**, in operation **1201**, a controller **130** generates a control signal for implementing a delay time for each of transducers included in a plurality of 2D transducer-arrays **110**.

In operation **1202**, an interposer **120** transmits the control signal generated in operation **1201** to each of a plurality of driving units **140** corresponding to the plurality of 2D transducer-arrays **110**. The plurality of 2D transducer-arrays **110** are electrically connected to each other via the interposer **120**.

In operation **1203**, the plurality of driving units **140** drive the plurality of 2D transducer-arrays **110** according to the control signal received in operation **1202**. Also, in this example, a signal to be transmitted from and a signal received by each of the transducers of the plurality of 2D transducer-arrays **110** may be delayed by using a same delay circuit provided for each of the transducers. In this case, the delay circuit may be the delayer **1411** of FIG. **5**. The delayer **1411** includes a plurality of delay lines and a plurality of switch devices that implement a transmitting delay time and receiving delay time according to the control signal.

Accordingly, the plurality of 2D transducer-arrays may be manufacturing using a plurality of 2D transducer-arrays enabling easy multi-channel expansion. Also, a beamforming apparatus having low complexity may be manufactured by using the plurality of 2D transducer-arrays **110**.

The controller **130**, the plurality of driving units **140**, and the diagnostic image generator **210** may be implemented using hardware components and/or software components. Software components may be implemented by a processing device, which may be implemented using one or more general-purpose or special-purpose computers, such as, for example, a processor, a controller and an arithmetic logic unit, a digital signal processor, a microcomputer, a field programmable array, a programmable logic unit, a microprocessor or any other device capable of responding to and executing instructions in a defined manner. The processing device may run an operating system (OS) and one or more software applications that run on the OS. The processing device also may access, store, manipulate, process, and create data in response to execution of the software. For purposes of simplicity, the description of a processing device is used as singular; however, one skilled in the art will appreciate that a processing device may include multiple processing elements and multiple types of processing elements. For example, a processing device may include multiple processors or a processor and a controller. In addition, different processing configurations are possible, such a parallel processors.

As used herein, a processing device configured to implement a function A includes a processor programmed to run specific software. In addition, a processing device configured to implement a function A, a function B, and a function C may include configurations, such as, for example, a processor configured to implement functions A, B, and C; a first pro-

cessor configured to implement function A and a second processor configured to implement functions B and C; a first processor configured to implement functions A and B and a second processor configured to implement function C; a first processor to implement function A, a second processor configured to implement function B, and a third processor configured to implement function C; a first processor configured to implement functions A, B, C and a second processor configured to implement functions A, B, and C, and so on.

The software may include a computer program, a piece of code, an instruction, or some combination thereof, for independently or collectively instructing or configuring the processing device to operate as desired. Software and data may be embodied permanently or temporarily in any type of machine, component, physical or virtual equipment, computer storage medium or device, or in a propagated signal wave capable of providing instructions or data to or being interpreted by the processing device. The software also may be distributed over network coupled computer systems so that the software is stored and executed in a distributed fashion.

In particular, the software and data may be stored by one or more non-transitory computer-readable storage mediums. The non-transitory computer-readable storage medium may include any data storage device that can store data that can be thereafter read by a computer system or processing device. Examples of a non-transitory computer-readable storage medium include read-only memory (ROM), random-access memory (RAM), CD-ROMs, magnetic tapes, floppy disks, and optical data storage devices. Also, functional programs, codes, and code segments for implementing the examples disclosed herein can be easily constructed by programmers skilled in the art to which the examples pertain based on the drawings and their corresponding descriptions as provided herein.

While this invention has been particularly shown and described with reference to various examples, it will be understood by those of ordinary skill in the art that various changes in form and details may be made in these examples without departing from the spirit and the scope of the invention as defined by the claims and their equivalents. The examples described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects in one example are to be considered as being applicable to similar features or aspects in other examples. Therefore, the scope of the invention is defined not by the detailed description of the invention, but by the claims and their equivalents, and all variations falling within the scope of the claims and their equivalents are to be construed as being included in the invention.

What is claimed is:

1. A beamforming apparatus comprising:
two-dimensional (2D) transducer-arrays, each 2D transducer-array comprising transducers in which analog beamforming is performed in a first direction of the 2D transducer-array and digital beamforming is performed in a second direction of the 2D transducer-array;
an interposer configured to electrically connect the two-dimensional (2D) transducer arrays transducer-arrays to each other;
a controller configured to
generate a control signal for implementing a delay time for the transducers of one or more of the two-dimensional (2D) transducer arrays transducer-arrays; and
output the control signal to the interposer; and
driving units corresponding to the two-dimensional (2D) transducer arrays transducer-arrays, each driving unit being configured to

receive the control signal from the interposer; and
drive a corresponding the two-dimensional (2D) transducer arrays transducer-array of the 2D transducer-arrays according to the control signal, wherein the interposer is between the two-dimensional (2D) transducer arrays transducer-arrays and the driving units corresponding to the 2D transducer-arrays.

2. The apparatus of claim 1, wherein each 2D transducer-array has a structure enabling the two-dimensional (2D) transducer arrays transducer-arrays to be arranged in a form of tiles;
each driving unit is disposed below a corresponding 2D transducer-array, and has a size enabling the two-dimensional (2D) transducer arrays transducer-arrays to be arranged in the form of tiles; and
the two-dimensional (2D) transducer arrays transducer-arrays are arranged in the form of tiles.

3. The apparatus of claim 1, wherein each driving unit comprises delayers corresponding to the transducers of a corresponding 2D transducer-array of the two-dimensional (2D) transducer arrays transducer-arrays; and
each delayer is configured to
delay a signal to be transmitted from a corresponding transducer; and
delay a signal received by the corresponding transducer.

4. The apparatus of claim 3, wherein the transducers of the two-dimensional (2D) transducer arrays transducer-arrays are arranged in rows of transducers and columns of transducers;
each delayer comprises delay lines configured to implement a transmitting delay time and a receiving delay time equal to the transmitting delay time for the corresponding transducer according to the control signal; and
the controller generates the control signal to implement a same transmitting delay time and a same receiving delay time for the transducers in one row of transducers or the transducers in one column of transducers to perform analog beamforming.

5. The apparatus of claim 4, wherein the delay lines comprise N sequentially arranged delay lines configured to implement a delay time of up to a minimum delay time period to the power of N, wherein N is an integer equal to or greater than '0'.

6. The apparatus of claim 4, wherein each delayer further comprises switch devices corresponding to the delay lines and each of the switch devices are disposed at an input terminal of a corresponding delay line;
each switch device is configured to selectively use or not use a corresponding delay line in implementing the transmitting delay time and the receiving delay time according to the control signal;
the controller generates the control signal to control the switch devices; and
the interposer transmits the control signal to the switch devices.

7. The apparatus of claim 3, wherein each driving unit further comprises switch devices corresponding to the delayers; and
each switch device is connected to an output terminal of a corresponding delayer, and is configured to:
switch a delayed signal output from the corresponding delayer to a first output of the switch device if the delayed signal is the delayed signal to be transmitted; and
switch the delayed signal output from the corresponding delayer to a second output of the switch device if the delayed signal is the delayed received signal.

8. The apparatus of claim **1**, wherein the transducers of each of the two-dimensional (2D) transducer arrays transducer-arrays are arranged in a horizontal direction and a vertical direction; and

the apparatus is configured to perform analog beamforming in the horizontal direction and digital beamforming in the vertical direction, or to perform digital beamforming in the horizontal direction and analog beamforming in the vertical direction.

9. The apparatus of claim **8**, further comprising a digital beamformer configured to perform the digital beamforming on results outputted from the driving units representing a receiving beam formed by performing the analog beamforming.

10. The apparatus of claim **8**, wherein the controller is configured to generate a control signal to implement a same delay time for digital beamforming for transducers disposed in the direction in which the analog beamforming is performed, and a control signal to implement a same delay time for analog beamforming for transducers disposed in the direction in which digital beamforming is performed.

11. The apparatus of claim **1**, wherein the interposer comprises a synthesizer configured to synthesize signals synthesized and outputted from the driving units.

12. The apparatus of claim **1**, wherein each 2D transducer-array of the two-dimensional (2D) transducer arrays transducer-arrays comprises a capacitive micromachined ultrasonic transducer (cMUT); and

each driving unit comprises an application specific integrated circuit (ASIC).

13. A beamforming method for two-dimensional (2D) transducer-arrays, the method comprising:

performing analog beamforming in a first direction and performing digital beamforming in a second direction of each of the two-dimensional (2D) transducer arrays transducer-arrays;

generating a control signal for implementing a delay time for transducers of one or more of the two-dimensional (2D) transducer arrays transducer-arrays;

transmitting the control signal to one or more driving units corresponding to the one or more of the two-dimensional (2D) transducer arrays transducer-arrays via an interposer that electrically connects the two-dimensional (2D) transducer arrays transducer-arrays to each other; and

driving the two-dimensional (2D) transducer arrays transducer-arrays with a corresponding driving unit of the driving units according to the control signal transmitted via the interposer, wherein the interposer is between the two-dimensional (2D) transducer arrays transducer-ar-

rays and the driving units corresponding to the two-dimensional (2D) transducer arrays transducer-arrays.

14. The method of claim **13**, wherein each driving unit comprises delayers corresponding to the transducers of a corresponding 2D transducer-array; and

the driving of each 2D transducer-array comprises

delaying a signal to be transmitted from each of the transducers with a corresponding delayer; and

delaying a signal received by each of the transducers with the corresponding delayer.

15. The method of claim **14**, wherein each delayer comprises delay lines configured to implement a transmitting delay time and a receiving delay time for a corresponding transducer according to the control signal, and switch devices corresponding to the delay lines and each of the switch devices is disposed at an input terminal of a corresponding delay line, and

each switch device is configured to selectively use or not use a corresponding delay line in implementing the transmitting delay time and the receiving delay time according to the control signal.

16. The method of claim **13**, wherein the transducers of the two-dimensional (2D) transducer arrays transducer-arrays are arranged in a horizontal direction and a vertical direction; and

the performing comprises performing analog beamforming in the horizontal direction and digital beamforming in the vertical direction, or performing digital beamforming in the horizontal direction and analog beamforming in the vertical direction.

17. A non-transitory computer-readable storage medium storing a computer program for controlling a processor to perform the method of claim **13**.

18. The apparatus of claim **1**, wherein the controller is configured to generate a control signal to implement a delay time based on the digital beamforming for transducers disposed in a direction in which the analog beamforming is performed.

19. The apparatus of claim **1**, wherein the controller is configured to generate a control signal to implement a delay time based on the analog beamforming for transducers disposed in a direction in which the digital beamforming is performed.

20. The apparatus of claim **1**, wherein the 2D transducer-arrays are arranged in an aperture shape.

21. The apparatus of claim **1**, wherein the interposer is directly between the two-dimensional (2D) transducer arrays transducer-arrays and the driving units corresponding to the two-dimensional (2D) transducer arrays transducer-arrays.

*   *   *   *   *